DEVELOPMENT OF A WEB-BASED EMISSIONS REDUCTION CALCULATOR FOR SOLAR THERMAL AND SOLAR PHOTOVOLTAIC INSTALLATIONS

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ABSTRACT

Four areas in Texas, involving 16 counties, have been designated by the United States Environmental Protection Agency (EPA) as non-attainment areas because ozone levels exceed the National Ambient Air Quality Standard (NAAQS) maximum allowable limits. These areas face severe sanctions if attainment is not reached by 2007. Four additional areas in the state, involving 25 counties, are also approaching national ozone limits (i.e., affected areas).

In 2001, the Texas State Legislature formulated and passed the Texas Emissions Reduction Plan (TERP), to reduce ozone levels by encouraging the reduction of emissions of NOx by sources that are currently not regulated by the state. Ozone results from photochemical reactions between oxides of Nitrogen (NOx) and volatile organic compounds (VOCs) in the presence of sunlight. An important part of this legislation is the State's energy efficiency program, which includes reductions in energy use and demand that are associated with the adoption of the 2000 International Energy Conservation Code (IECC), including the 2001 Supplement (IECC 2000, 2001) which represents one of the first times that the EPA is considering State Implementation Plan (SIP) credits from energy conservation and renewable energy– an important new development for building efficiency professionals, since this could pave the way for documented procedures for financial reimbursement for building energy conservation from the state's emissions reductions funding.

This paper presents the procedure that have been developed and used to assess the potential emission reductions due to the electricity savings from the application of some of the most common solar thermal and solar photovoltaic systems. The methodology to estimate the potential NOx emission reduction integrates legacy analysis tools, including the F-CHART[1], PV-FCHART[2]. ASHRAE's Inverse Model Toolkit (IMT)[3] is used to perform the weather normalization, and for calculating peak-day electricity savings. The EPA's Emissions and Generations Resource Integrated Database (eGRID)[4] is used for calculating the NO_x emissions reductions for the electric utility provider associated with the user.

INTRODUCTION

In 2001, the Texas State Legislature formulated and passed Senate Bill 5 to further reduce ozone levels by encouraging the reduction of emissions of NOx by sources that are currently not regulated by the state, including area sources (e.g., residential emissions), on-road mobile sources (e.g., all types of motor vehicles), and non-road mobile sources (e.g., aircraft, locomotives, etc.)[5]. An important part of this legislation is the evaluation of the State's new energy efficiency programs, which includes reductions in energy use and demand that are associated with specific utility-based energy conservation measures, and implementation of the IECC, published in 2000 as amended by the 2001 Supplement (IECC 2000; 2001). In 2001, thirty-eight counties in Texas were designated by the EPA as either non-attainment or affected areas[6]. In 2003, three additional counties

[1] F-CHART is the well known solar thermal design method, developed by the University of Wisconsin, which is used to select and analyze solar thermal systems. The program provides monthly-average performance for selected system, including: domestic water heating systems, space heating systems, pool heating systems and others (Klein and Beckman 1983).

[2] PV F-CHART is the well known solar photovoltaic system analysis and design program. The program provides an hourly performance profile for monthly-average days. The calculations are also based upon methods developed at the University of Wisconsin, which use the utilizability concept to account for the statistical variation of radiation and load (Klein and Beckman 1985).

[3] IMT, the Inverse Model Toolkit, is a FORTRAN 90 application that performs regression modeling of building energy use. Its development was sponsored by ASHRAE 1050-RP in support of ASHRAE GUIDELINE 14-2002. IMT is capable of identifying traditional linear, least-squares regression models. It is also capable of identifying special change-point and variable-base degree-day models that have been shown to be especially useful for modeling building energy use (Kissock et al. 2002).

[4] eGRID, ver. 2, is the EPA's emissions and generation resource integrated database. This publicly available database can be found at *www.epa.gov/airmarkets/egrid/*.

[5] In the 2003 Texas State legislative session, the emissions reductions legislation in Senate Bill 5 was modified by House bill 3235, and House bill 1365. In general, this new legislation strengthened the previous legislation, and did not reduce the stringency of the building code or the reporting of the emissions reductions.

[6] The sixteen counties designated as non-attainment counties include: Brazoria, Chambers, Collin, Dallas, Denton, El Paso, Fort

were classified as affected counties[7], bringing the total to forty-one counties (sixteen non-attainment and twenty-five affected counties) out of the 254 counties in Texas. On February 2004, the TCEQ issued a document entitled "Incorporating Energy Efficiency/Renewable Energy (EE/RE) Projects into the SIP: A Guide for Local Entities", which provides guidance on how political subdivisions can assist the TCEQ in taking credit for emissions reductions from energy efficiency measures implemented at the political subdivision level. According to this TCEQ guidance, energy efficiency, renewable energy and no-emission distributed generation strategies that may be considered for inclusion as SIP measures include, among others, the Local Distributed Generation Solar Photo-Voltaic (PV) Installations and the Local Distributed Generation Solar Thermal Installations.

This paper describes a methodology to evaluate the potential emissions reduction that the implementation of solar systems could achieve. The analysis of the solar thermal and solar photovoltaic performance is made using the F-CHART and PV F-CHART software respectively, and is perhaps the most commercial customary accepted software for this purpose, which was developed by the University of Wisconsin for the U.S. Department of Energy (Klein and Beckman, 1983).

METHODOLOGY

To calculate NOx emissions from the installation of solar energy systems, two analyses were created: one procedure for calculating annual and peak-day[8] electricity savings from photovoltaic systems using the PV F-CHART program, and a second procedure that uses the F-CHART program to calculate the thermal savings. The solar systems are simulated as specified for the user, no optimization or modification is implemented by the emissions calculator. Both procedures required the use of the ASHRAE Inverse Model Toolkit (IMT), to normalize annual and peak-day emissions savings to a base year that was different from the weather data contained in the PV F-CHART and F-CHART program. Therefore the potential of emissions reduction can be calculated for the year, or period, that the user is interested.

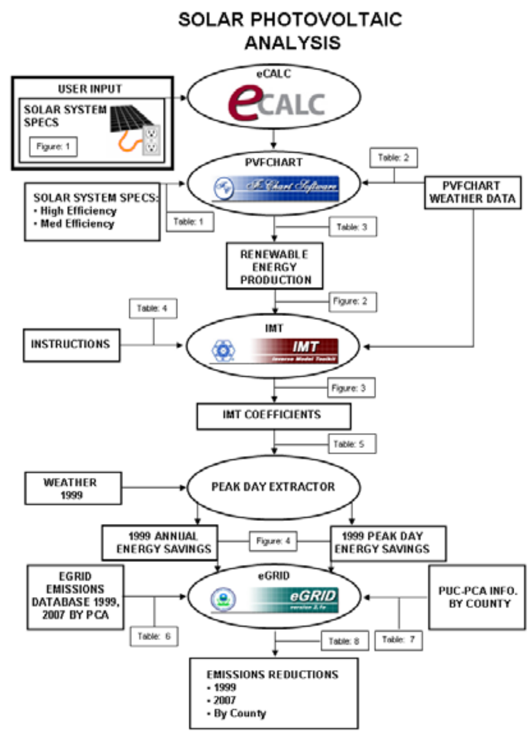


Figure 1. Solar Photovoltaic Analysis Flowchart

Solar PV Analysis Description

The procedure for a solar photovoltaic system offers energy analyses for two types of solar photovoltaic systems: a high-efficiency system, and an average efficiency system[9]. Both systems are analyzed with the PV F-CHART software. The methodology for the evaluation of the potential emissions reduction due to the implementation of a solar photovoltaic system is composed of several major steps (see Figure 1). The first step calculates the levels of electricity that a specific photovoltaic system can generate at a given location, considering the orientation and tilt of the collectors. In the next step, the electricity output from the system is weather-normalized using a temperature-based regression. The resultant parameters from this step are then used to calculate the annual electricity

Bend, Hardin, Harris, Jefferson, Galveston, Liberty, Montgomery, Orange, Tarrant, and Waller counties. The twenty-two counties designated as affected counties include: Bastrop, Bexar, Caldwell, Comal, Ellis, Gregg, Guadalupe, Harrison, Hays, Johnson, Kaufman, Nueces, Parker, Rockwall, Rusk, San Patricio, Smith, Travis, Upshur, Victoria, Williamson, and Wilson County.

[7] These counties are Henderson, Hood and Hunt counties in the Dallas – Fort Worth area.

[8] The peak day savings calculations are required by the EPA for the prediction of NOx emissions reductions on a peak ozone day, which can represent a specific peak day during the base year (i.e., August 19th, 1999), or an average day across the ozone episode period (i.e., July 15th to September 15th for Texas).

[9] The average efficiency system, which is identified as a low-end system in the eCalc, comes from the characteristics of the Solarex-10 that has an average efficiency of 0.057, constructed of poly-crystalline silicon cells. The high-end efficiency system data comes from the Shell SP75, which has a reported average efficiency 0.1184 and is made of silicon mono-crystalline photovoltaic cells

production during the base year and to extract the peak Ozone Season Period electricity production, which is used to calculate emissions reductions using eGRID.

Table 1. Photovoltaic system specifications in the PV F-CHART [10] format (corresponding to the Table 1 of the Solar Photovoltaic Analysis Flowchart).

```
                    ** Stand Alone System **

1  City number for AUSTIN          TX...............  18
2  Output: 1 for summary, 2 for detailed (Neg: graph)  1
3  Cell temperature at NOCT conditions..............  113   F
4  Array reference efficiency.......................  .1184
5  Array reference temperature......................  77    F
6  Max. power eff. temperature coeff. (times 1000)...  2.5   1/F
7  Eff. of maximum power point tracking electronics..  .9
8  Efficiency of power conditioning electronics......  .88
9  Percent standard deviation of the load...........  0     %
10 Array area.......................................  60    ft^2
11 Array slope......................................  50    deg
12 Array azimuth (south=0)..........................  0     deg
```

Table 2. Typical PV F-CHART weather data (corresponding to the Table 2 of the Solar Photovoltaic Analysis Flowchart).

AUSTIN	TX	LAT= 30				
	SOLAR BTU/FT2	TEMP F	T SKY F	MAINS	REFLEC	HUMID LB/LB
JAN	945	48.2	22.0	66.4	0.2	0.0057
FEB	1199	52.3	24.9	66.6	0.2	0.0057
MAR	1498	60.6	40.6	67.0	0.2	0.0094
APR	1717	68.5	53.6	67.4	0.2	0.0124
MAY	1869	74.3	60.6	67.7	0.2	0.0132
JUN	2092	80.2	68.2	68.0	0.2	0.0159
JUL	2152	83.3	71.3	68.1	0.2	0.0167
AUG	2005	83.5	70.6	68.2	0.2	0.0159
SEP	1663	78.1	65.6	67.9	0.2	0.0151
OCT	1383	69.3	51.6	67.4	0.2	0.0117
NOV	1049	59.4	37.3	67.0	0.2	0.0082
DEC	883	51.1	25.0	66.5	0.2	0.0057

Table 3. PV F-CHART output data (corresponding to the Table 3 of the Solar Photovoltaic Analysis Flowchart).

	Solar kWh	Load kWh	F %	Buy kWh	XS kWh
Jan	722.1	0.0	100.0	0.0	64.0
Feb	717.8	0.0	100.0	0.0	62.6
Mar	850.8	0.0	100.0	0.0	71.6
Apr	804.3	0.0	100.0	0.0	65.9
May	789.5	0.0	100.0	0.0	63.4
Jun	801.7	0.0	100.0	0.0	62.9
Jul	872.1	0.0	100.0	0.0	67.9
Aug	915.6	0.0	100.0	0.0	71.7
Sep	866.0	0.0	100.0	0.0	69.3
Oct	903.5	0.0	100.0	0.0	74.5
Nov	756.5	0.0	100.0	0.0	65.0
Dec	702.0	0.0	100.0	0.0	61.9
Yr	9701.9	0.0	100.0	0.0	800.8

[10] For additional details on the meaning of some input and output parameters presented in Tables 1,2, and 3 refer to PVFCHART manual

Table 4. Input file parameters into Inverse Modeling Toolkit[11] (corresponding to the Table 4 of the Solar Photovoltaic Analysis Flowchart).

```
Path and name of input data file = dflt_fchart.prn
Value of no-data flag = -99
Column number of group field = 0
Value of valid group field = 1
Residual file needed (1 yes, 0 no) = 1
Model type (1:Mean,2:2p,3:3pc,4:3ph,5:4p,6:5p,7:MVR,8:HDD,9:CDD) = 4
Column number of dependent Y variable = 7
Number of independent X variables (0 to 6)  = 1
Column number of independent variable X1 = 1
Column number of independent variable X2 = 0
Column number of independent variable X3 = 0
Column number of independent variable X4 = 0
Column number of independent variable X5 = 0
Column number of independent variable X6 = 0
```

Table 5. Model parameters from IMT program (corresponding to the Table 5 of the Solar Photovoltaic Analysis Flowchart).

```
********************************************
 ASHRAE INVERSE MODELING TOOLKIT (1.9)
 ********************************************
   Output file name = IMT.Out
 ********************************************
   Input data file name =  dflt_fchart.prn
   Model type =           3P Heating
   Grouping column No =    0
   Value for grouping =    1
   Residual mode =         1
   # of X(Indep.) Var =    1
   Y1 column number =      6
   X1 column number =   1
   X2 column number =   0 (unused)
   X3 column number =   0 (unused)
   X4 column number =   0 (unused)
   X5 column number =   0 (unused)
   X6 column number =   0 (unused)
 ********************************************
   Regression Results
  --------------------------------------
          N =      12
  --------------------------------------
         R2 =      0.251
  --------------------------------------
      AdjR2 =      0.251
  --------------------------------------
       RMSE =       0.1143
  --------------------------------------
    CV-RMSE =      5.208%
  --------------------------------------
          p =      0.436
  --------------------------------------
         DW =      1.015 (p>0)
  --------------------------------------
         N1 =       3
  --------------------------------------
         N2 =       9
  --------------------------------------
        Ycp =       2.2254 (       0.0371)
  --------------------------------------
         LS =       0.0311 (       0.0170)
  --------------------------------------
         RS =       0.0000 (       0.0000)
  --------------------------------------
        Xcp =      54.5540 (       0.7060)
  --------------------------------------
  --------------------------------
```

When a user submits a solar photovoltaic project for analysis, the emissions calculator takes the information provided by the user along with tables of additional information and calls the PV F-CHART program. The Table 1 shows a portion of the PV F-CHART input file, and the Table 2 shows an example of the weather data from the PV F-CHART program. The PV F-CHART program calculates the monthly

[11] For additional details on the meaning of some input and output parameters presented in Tables 4 and 5 refer to IMT manual

electricity produced by the system at the latitude and weather data associated with the user's county, using PV F-CHART's average weather data from the nearest location (Table 3). In the next step, the emissions calculator takes the resultant 12 months of calculated electricity production from the photovoltaic system and creates weather-normalized coefficients that can then be applied to the base-year 1999 weather data. This is accomplished with the ASHRAE IMT. The Table 4 provides an example of the instruction file for the IMT, and Table 5 provides an example of an output from the IMT program, from which the coefficients of the regression are extracted. The Figure 2 depicts a typical time-series plot of predicted electricity production from the PV F-CHART. The Figure 3 shows the same electricity production plotted against the average monthly temperature, and includes an overlay of IMT's 3-parameter regression, which is used to predict monthly and peak-day electricity production. The Figure 4 portrays the annual electricity production for the 1999 base year, including the peak-day electricity production. These calculations are accomplished by applying IMT's coefficients to the base year daily temperature data. In the next step of the emissions calculator computes the NO_x, emissions reductions using the EPA's eGRID database. The results are then reported by the emissions calculator in a similar format to that shown in the Figure 8, as HTML and XML files.

<u>Solar photovoltaic input screens</u>

The Figure 5 illustrates the main eCALC screen that include modules for New Buildings (i.e., single-family, multi-family, office, retail); Community Projects (i.e., municipal buildings, street lights, traffic lights, water and waste water supply); and Renewables (i.e., solar PV, solar thermal, wind).

The screens for solar photovoltaic projects begin with the project input screen shown in Figure 6. In this input screen, the user is asked for the general information about the systems, i.e. the type of PV system, a high or an average efficiency system. In addition, the screen has field spaces for a project name, an email address to where the output will be sent, and a link button to the next screen (Figure 7). This next input screen asks for the minimum information about the installation of the solar photovoltaic system, including: the area of the array, the slope of the array as measured from the horizontal, and what is the deviation from the south the collector array is facing (i.e., array azimuth). After completion of the screens, the project is submitted for analysis.

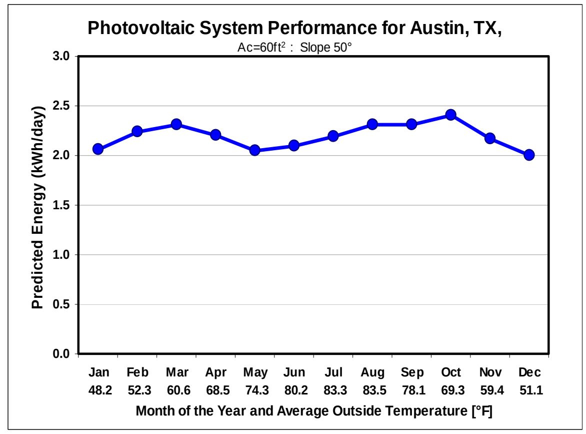


Figure 2. Renewable energy production photovoltaic solar system (corresponding to the Figure 2 of the Solar Photovoltaic Analysis Flowchart).

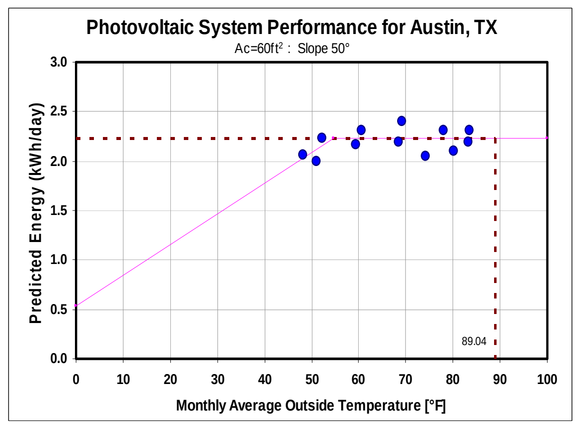


Figure 3. Representation of the 3P model output from IMT for a photovoltaic solar system (corresponding to the Figure 3 of the Solar Photovoltaic Analysis Flowchart).

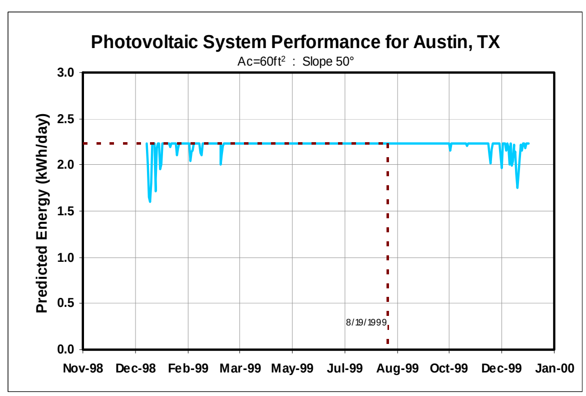


Figure 4. Annual and Peak Day Energy Savings of a photovoltaic solar system (corresponding to the Figure 4 of the Solar Photovoltaic Analysis Flowchart).

Figure 5. Emissions Reduction Calculator eCALC Main Screen.

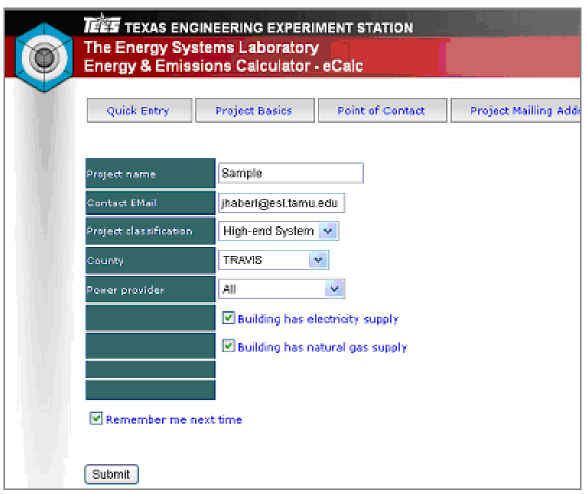


Figure 6. Project information screen of a solar photovoltaic system.

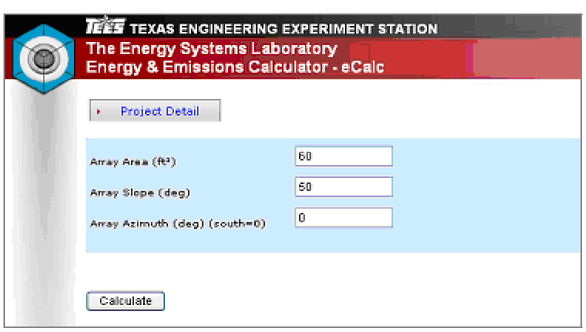
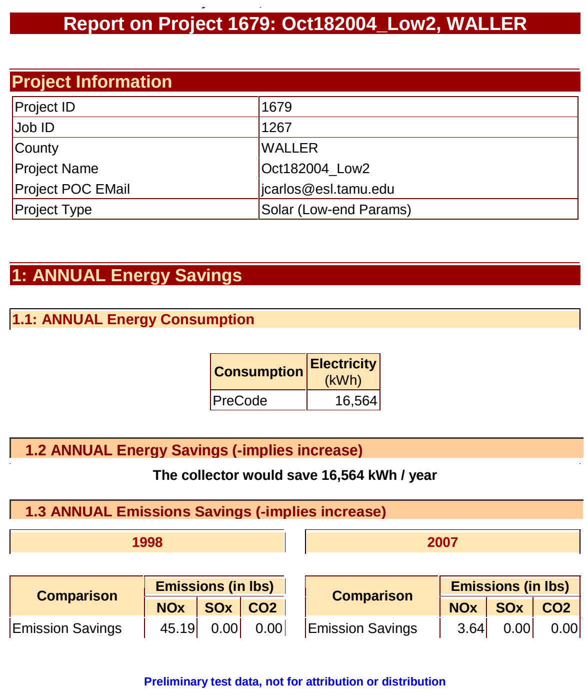


Figure 7. Project installation detail screen of a solar photovoltaic system.



Report on Project 1679: Oct182004_Low2, WALLER

Project Information

Project ID	1679
Job ID	1267
County	WALLER
Project Name	Oct182004_Low2
Project POC EMail	jcarlos@esl.tamu.edu
Project Type	Solar (Low-end Params)

1: ANNUAL Energy Savings

1.1: ANNUAL Energy Consumption

Consumption	Electricity (kWh)
PreCode	16,564

1.2 ANNUAL Energy Savings (-implies increase)

The collector would save 16,564 kWh / year

1.3 ANNUAL Emissions Savings (-implies increase)

1998

Comparison	Emissions (in lbs) NOx	SOx	CO2
Emission Savings	45.19	0.00	0.00

2007

Comparison	Emissions (in lbs) NOx	SOx	CO2
Emission Savings	3.64	0.00	0.00

Preliminary test data, not for attribution or distribution

Figure 8. Web output of the energy and potential emission reduction due to a photovoltaic system installation (corresponding to the Table 8 of the Solar Photovoltaic Analysis Flowchart).

Solar Thermal Analysis Description (DHW and pool heating systems)

The methodology for the evaluation of the potential emissions reduction due to the implementation of a solar thermal system, which is similar to the solar photovoltaic system analysis, is also composed of several steps. The first step calculates thermal energy provided by the user's solar thermal system, and includes two system types: a domestic water heating (DHW), and pool heating systems. In the second step, ASHRAE's IMT is used to develop coefficients that weather-normalize the system's output versus temperature. These coefficients are then used to generate the annual and peak day thermal output for the base year. This base-year thermal energy production is then converted into emissions reductions using the EPA's eGRID database[12].

[12] For solar systems that displace natural gas use, NOx values for a natural gase-fired water heater are used which incorporate the EPA's AP 42 data.

Table 6. Solar collector specifications for: (a) Pool heating system and (b) Water Storage System (corresponding to the Table 1 of the Solar Thermal Analysis Flowchart). For additional details on the meaning of some input and output parameters presented in Tables 6, 7, and 8 refer to FCHART manual.

(a)	(b)
*** POOL HEATING SYSTEM ***	*** WATER STORAGE SYSTEM ***
1 City call number.............. 14	1 City call number.............. 14
2 Pool surface area............. 540 FT2	2 Water storage volume.......... 1000 GALLONS
3 Pool temperature.............. 80 F	3 Building UA (0 for DHW only).. 0 BTU/HR-F
4 First month of use (1-12)..... 1	4 Fuel (1=EL,2=NG,3=OIL,4=OTHER) 1
5 Last month of use (1-12)...... 12	5 Efficiency of fuel usage...... 100 %
6 Cover (0=None,1=Film,2=Bubble) 2	6 Domestic hot water (1=Y,2=N).. 1
7 Hours per day covered......... 12 HR/DAY	7 Daily hot water usage....... 60 GALLONS
8 Average pool depth............ 5 FT	8 Water set temperature....... 140 F
9 Location (1=Indoor, 2=Outdoor) 1	9 Environment temperature..... 68 F
10 % of time shaded.....(Outdoor) 0 %	10 DHW storage tank size....... 80 GALLONS
11 Average windspeed...(Outdoor) 5 MILES/HR	11 UA of aux storage tank...... 7.6 BTU/HR-F
12 Pool room rel humidity(Indoor) 50 %	12 Pipe heat loss (1=Y,2=N)...... 2
13 Pool room temperature (Indoor) 75 F	13 Inlet pipe UA............... 5 BTU/HR-F
14 Fuel (1=EL,2=NG,3=OIL,4=OTHER) 2	14 Outlet pipe UA.............. 5 BTU/HR-F
15 Efficiency of fuel usage...... 70 %	15 Relative load HX size......... 1
16 Pipe heat loss (1=Y,2=N)...... 2	16 Collector-storage HX (1=Y,2=N) 2
17 Inlet pipe UA............... 5 BTU/HR-F	17 Tank side flowrate/area..... 11 LB/HR-FT2
18 Outlet pipe UA.............. 5 BTU/HR-F	18 Heat exchanger effectiveness .5
** FLAT PLATE COLLECTOR **	** FLAT PLATE COLLECTOR **
1 Number of collector panels.... 60	1 Number of collector panels.... 60
2 Collector panel area.......... 1 FT2	2 Collector panel area.......... 1 FT2
3 FR*UL (test slope)............ 2.9 BTU/HR-FT2-F	3 FR*UL (test slope)............ 1.07 BTU/HR-FT2-F
4 FR*TAU*ALPHA (test intercept). .84	4 FR*TAU*ALPHA (test intercept). .78
5 Collector slope............... 45 DEG	5 Collector slope............... 45 DEG
6 Collector azimuth (South=0)... 0 DEG	6 Collector azimuth (South=0)... 0 DEG
7 Incidence angle mod TYPE(8-10) 8	7 Incidence angle mod TYPE(8-10) 8
8 Number of glazings.......... 0	8 Number of glazings.......... 1
9 Inc angle modifier constant. 0	9 Inc angle modifier constant. 0
10 Inc angle modifier value(s).	10 Inc angle modifier value(s).
1 .999 .998 .995 .981 .953 .882 .7 .35 0	1 .999 .998 .995 .981 .953 .882 .7 .35 0
11 Collector flowrate/area....... 11 LB/HR-FT2	11 Collector flowrate/area....... 11 LB/HR-FT2
12 Collector fluid specific heat. 1 BTU/LB-F	12 Collector fluid specific heat. 1 BTU/LB-F
13 Modify test values (1=Y,2=N).. 2	13 Modify test values (1=Y,2=N).. 2
14 Test collector flowrate/area 11 LB/HR-FT2	14 Test collector flowrate/area 11 LB/HR-FT2
15 Test fluid specific heat.... 1 BTU/LB-F	15 Test fluid specific heat.... 1 BTU/LB-F

When a user submits a solar thermal project for analysis, the emissions calculator takes the information provided by the user and tables of additional information, and calls the F-CHART program. The Table 6 shows an example of the input parameters for the F-CHART program, including the information required by the pool and domestic water heating system. The Table 7 presents some of the ambient conditions provided by the F-CHART program, including average-year solar radiation, ambient temperature, sky temperature, water supply temperature, ground reflectivity and humidity ratio. The F-CHART program then calculates the monthly thermal energy produced by the system specified by the user at the latitude associated with the county selected by the user using F-CHART's weather data from the nearest location (Table 7). In the next step, the emissions calculator takes the 12 months of calculated thermal energy produced by the solar collector system (Table 8) and, using the ASHRAE IMT, calculates the coefficients to weather-normalized the thermal energy production against average monthly temperature. These coefficients are then applied to the 1999 weather data to calculate the annual and peak day thermal production in the 1999 base year. The Table 9 contains the input instructions for the IMT program, and Table 10 presents the results from the IMT for a regression of solar thermal energy use against average monthly temperature. The Figure 10 depicts the thermal energy production of the user's system calculated by the F-CHART program. The Figure 11 shows the thermal output from the solar system plotted against the average daily temperature for, and includes the 3-parameter model calculated with the IMT. The coefficients from the IMT are then used to calculate the total annual and peak day production for the 1999 base year. The results are then reported by the emissions calculator in a format that is similar to that shown in Figure 19 and emailed to the user as HTML and XML files.

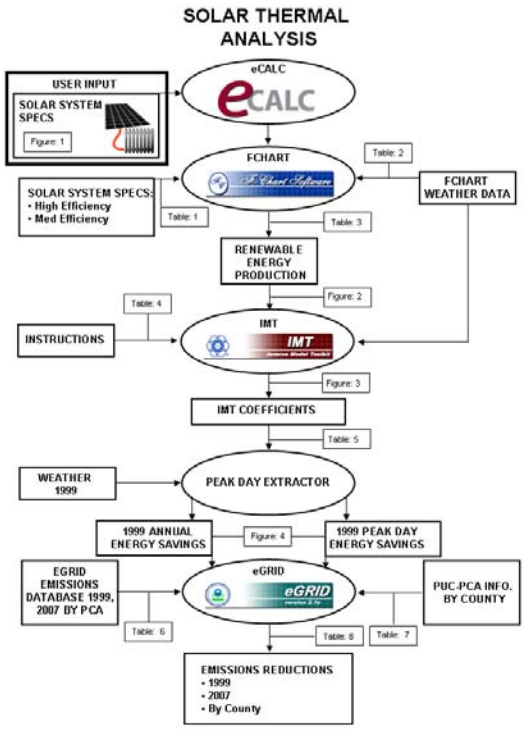


Figure 9. Solar Thermal Analysis Flowchart.

Table 7. Typical F-CHART weather data (corresponding to the Table 2 of the Solar Thermal Analysis Flowchart).

AUSTIN TX LAT= 30						
	SOLAR BTU/FT2	TEMP F	T SKY F	MAINS	REFLEC	HUMID LB/LB
JAN	945	48.2	22.0	66.4	0.2	0.0057
FEB	1199	52.3	24.9	66.6	0.2	0.0057
MAR	1498	60.6	40.6	67.0	0.2	0.0094
APR	1717	68.5	53.6	67.4	0.2	0.0124
MAY	1869	74.3	60.6	67.7	0.2	0.0132
JUN	2092	80.2	68.2	68.0	0.2	0.0159
JUL	2152	83.3	71.3	68.1	0.2	0.0167
AUG	2005	83.5	70.6	68.2	0.2	0.0159
SEP	1663	78.1	65.6	67.9	0.2	0.0151
OCT	1383	69.3	51.6	67.4	0.2	0.0117
NOV	1049	59.4	37.3	67.0	0.2	0.0082
DEC	883	51.1	25.0	66.5	0.2	0.0057

Table 8. F-CHART output data (corresponding to the Table 3 of the Solar Thermal Analysis Flowchart).

*** POOL HEATING SYSTEM *** ** FLAT PLATE COLLECTOR **						
	QCOLL MMBTU	QPOOL MMBTU	LOAD MMBTU	AUX MMBTU	F	Renewabl kBtu/day
JAN	0.8	12.4	35.0	34.1	0.02	29.032
FEB	1.0	14.2	26.9	25.9	0.04	35.714
MAR	1.5	19.6	14.4	12.9	0.10	48.387
APR	1.7	21.8	1.8	0.0	0.99	60.000
MAY	2.0	24.5	0.0	0.0	1.00	0.000
JUN	2.4	26.5	0.0	0.0	1.00	0.000
JUL	2.7	28.2	0.0	0.0	1.00	0.000
AUG	2.7	26.3	0.0	0.0	1.00	0.000
SEP	2.4	21.1	0.0	0.0	1.00	0.000
OCT	2.0	18.1	7.4	5.3	0.28	67.742
NOV	1.3	13.3	22.3	21.0	0.06	43.333
DEC	0.9	11.6	34.2	33.3	0.03	29.032
YR	21.5	237.6	141.8	132.5	0.07	

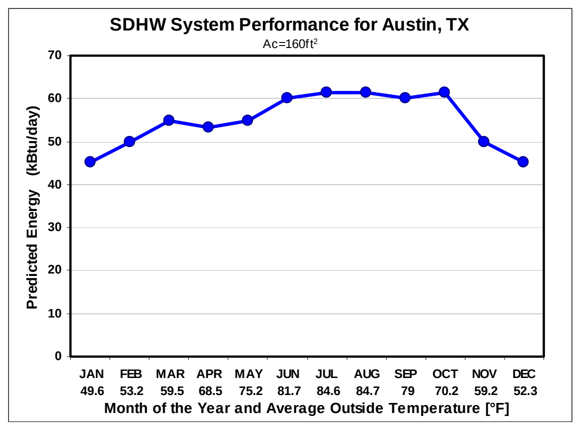


Figure 10. Renewable energy production of a solar domestic how water system (corresponding to the Figure 2 of the Solar Thermal Analysis Flowchart).

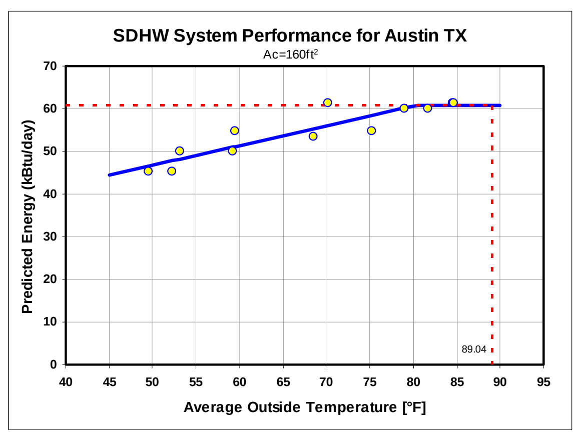


Figure 11. Representation of the 3P model output from IMT for a solar DHW system (corresponding to the Figure 3 of the Solar Thermal Analysis Flowchart).

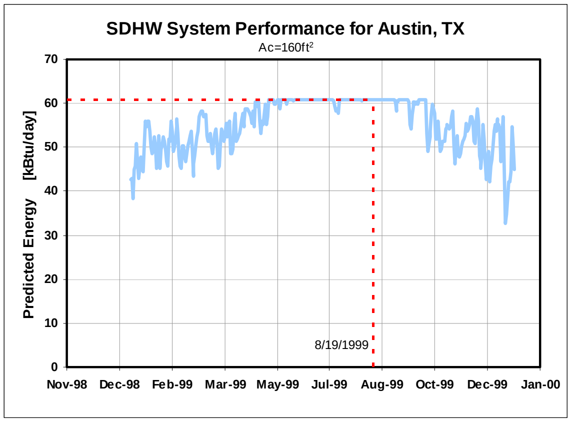


Figure 12. Annual and peak-day energy savings of a solar DHW system (corresponding to the Figure 4 of the Solar Thermal Analysis Flowchart).

Table 9. Parameters input file into Inverse Modeling Toolkit IMT (corresponding to the Table 4 of the Solar Thermal Analysis Flowchart).

```
Path and name of input data file = dflt_fchart.prn
Value of no-data flag = -99
Column number of group field = 0
Value of valid group field = 1
Residual file needed (1 yes, 0 no) = 1
Model type (1:Mean,2:2p,3:3pc,4:3ph,5:4p,6:5p,7:MVR,8:HDD,9:CDD) = 4
Column number of dependent Y variable = 7
Number of independent X variables (0 to 6)  = 1
Column number of independent variable X1 = 1
Column number of independent variable X2 = 0
Column number of independent variable X3 = 0
Column number of independent variable X4 = 0
Column number of independent variable X5 = 0
Column number of independent variable X6 = 0
```

Solar thermal - pool heating system input screens

The user input screens for solar thermal pool heating projects begin with the project input screen shown in Figure 13. In this input screen, the user is asked for their project name, their email address, what type of solar system this is; DHW or pool heating. When the user submits the project information to the emissions calculator, they are directed to the next screen for solar thermal projects shown in Figure 14. This input screen asks for specific information about the array of solar thermal collectors, including the area of the array, the slope of the array as measured from the horizontal, and whether the collector array is facing south (i.e., array azimuth). When the user completes the screen shown in Figure 14, they have the option of revising additional default information about pools, as shown in Figure 15. The additional information refers to the characteristics of the pool; surface area, depth, temperature, type of cover (if any), hours per day covered, location, and its shading. When the user completes the data entry requested in Figure 15 and submits the project for calculation, the emissions calculator computes the thermal energy required by the solar thermal pool heating system and emails the emissions output to the address the user entered in the project information screen.

Table 10. Model parameters from IMT[13] output (corresponding to the Table 5 of the Solar Thermal Analysis Flowchart).

```
SWIMMING POOL SOLAR SYSTEM

 --------------------------------------
  ASHRAE INVERSE MODELING TOOLKIT (1.9)
 ********************************************
    Output file name = IMT.Out
 ********************************************
    Input data file name =  dflt_fchart.prn
    Model type =             4P
    Grouping column No =      0
    Value for grouping =      1
    Residual mode =           1
    # of X(Indep.) Var =      1
    Y1 column number =        2
    X1 column number =     1
    X2 column number =     0 (unused)
    X3 column number =     0 (unused)
    X4 column number =     0 (unused)
    X5 column number =     0 (unused)
    X6 column number =     0 (unused)
 ********************************************
    Regression Results
   -------------------------------------
          N =      12
   -------------------------------------
         R2 =      0.987
   -------------------------------------
      AdjR2 =      0.987
   -------------------------------------
       RMSE =       2.8479
   -------------------------------------
    CV-RMSE =      4.844%
   -------------------------------------
          p =      0.084
   -------------------------------------
         DW =      1.762 (p>0)
   -------------------------------------
         N1 =       8
   -------------------------------------
         N2 =       4
   -------------------------------------
        Ycp =      68.6995 (      10.3949)
   -------------------------------------
         LS =       1.6155 (       0.1069)
   -------------------------------------
         RS =       2.1659 (       0.3879)
   -------------------------------------
        Xcp =      74.3220 (       0.7060)
   -------------------------------------
  ---------------------------------
```

Solar thermal - DHW system input screens

The user input screens for solar thermal domestic water heating (DHW) projects begin with the project input screen shown in Figure 16. In this input screen, the user is asked for the project name, an email address, and the type of solar system (i.e. DHW or pool heating). When the project information is submitted to the emissions calculator, it directs to the screen for solar thermal projects shown in Figure 17. This input screen requires the minimum necessary information about the solar system, including the area, the slope as measured from the horizontal, and

[13] For additional details on the meaning of some input and output parameters presented in Tables 9 and 10 refer to IMT manual

the angular deviation from the south the solar collector array is facing (i.e. array azimuth). After solar characteristics are input, users have the option of revising additional default information about the DHW system, as shown in Figure 18, which includes information about the daily hot water usage and DHW storage tank size. When the user completes the data entry requested in Figure 18 and submits the project for calculation, the emissions calculator then calculates the thermal energy produced by the solar thermal DHW system and emails the output to the address the user entered in the project information screen. In the next step of the analysis, the emissions calculator evaluates the NO_x, using the EPA's eGRID database in a format similar to that shown in Figure 19.

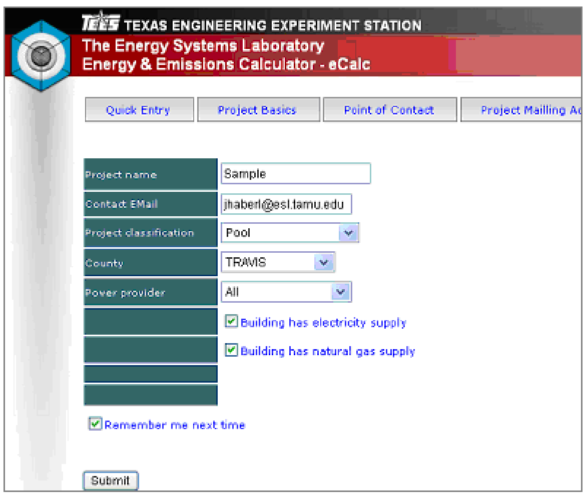


Figure 13. Project info screen of a Solar Thermal - Pool Heating System

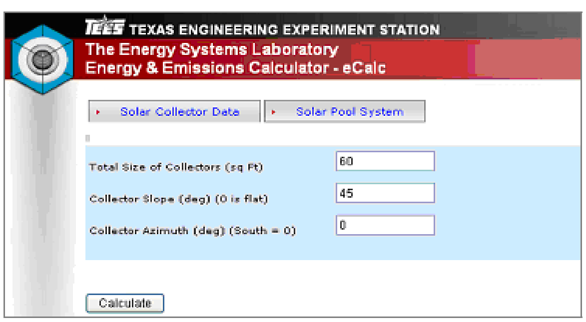


Figure 14. Project info screen of a Solar Thermal - Pool Heating System

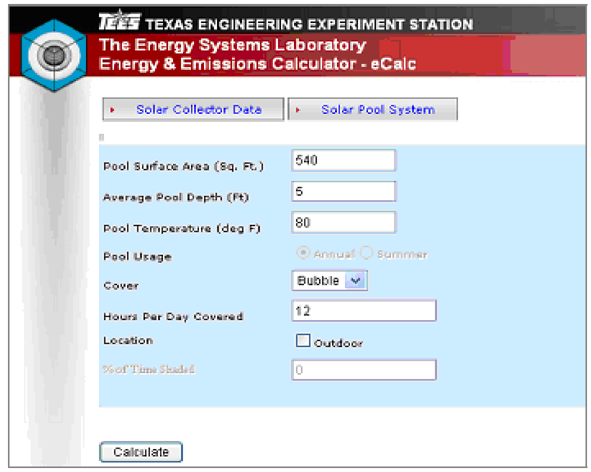


Figure 15. Solar collector input screen of a Solar Thermal - Pool Heating System

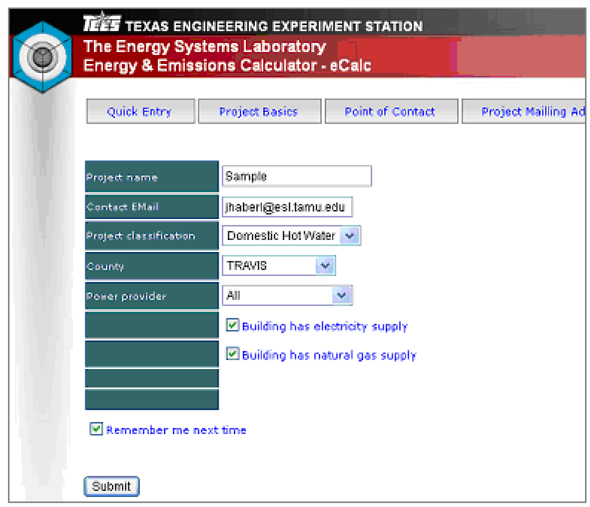


Figure 16:. Project info screen of a Solar Thermal - DHW Heating System

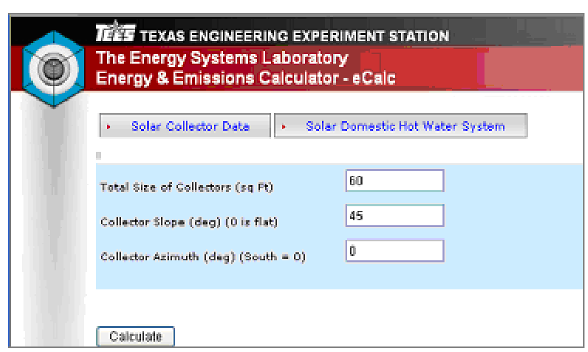


Figure 17. Solar collector info screen of a Solar Thermal - DHW Heating System.

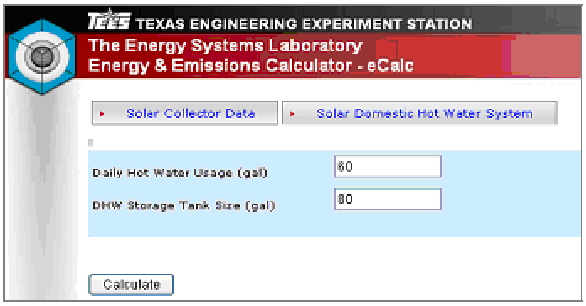


Figure 18. Domestic water heating info screen of a Solar Thermal - DHW Heating System.

Project Information

Project ID	1673
Job ID	1264
County	WALLER
Project Name	Default_Run88_low
Project POC EMail	jcarlos@esl.tamu.edu
Project Type	Solar - Pool

1: ANNUAL Energy Savings

1.1: ANNUAL Energy Consumption

Consumption	Electricity (kWh)
PreCode	6,294

1.2 ANNUAL Energy Savings (-implies increase)

The collector would save 6,294 kWh / year

1.3 ANNUAL Emissions Savings (-implies increase)

1998

Comparison	Emissions (in lbs)		
	NOx	SOx	CO2
Emission Savings	17.17	0.00	0.00

2007

Comparison	Emissions (in lbs)		
	NOx	SOx	CO2
Emission Savings	1.38	0.00	0.00

Figure 19. Web output of the energy and potential emission reduction due to a solar heating system (corresponding to the Table 8 of the Solar Thermal Analysis Flowchart).

SUMMARY

This paper has described the methods that have been developed to calculate annual and peak day potential NOx emissions reduction from solar thermal and photovoltaic systems using the F-CHART and PV F-CHART programs, and includes the procedures used to weather-normalize the calculated thermal or electricity production to the 1999 base year using ASHRAE's Inverse Model Toolkit (IMT). Additional information about these procedures can be found in Haberl et al. (2004a, b, c), by visiting the emissions calculator "ecalc.tamu.edu", or by visiting the Laboratory's Senate Bill 5 web site "eslsb5.tamu.edu".

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